DESIGN AND DEVELOPMENT

OF A SOLAR CLOTH DRYER

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

In

Mechanical Engineering

By

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DEPARTMENT OF MECHANICAL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
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CERTIFICATE

This is to certify that the thesis entitled "**DESIGN AND DEVELOPMENT OF A SOLAR CLOTH DRYER**" submitted by Mr. Shaik Zuneid Alam in partial fulfillment of the requirements for the award of Bachelor of technology Degree in Mechanical Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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ACKNOWLEDGEMENT

I would like to express my deep sense of gratitude to my supervisor,Prof. S Murugan,for his excellent guidance,suggestions and constructive criticisms.His suggestions and support throughout the entire project has helped me come out successfully designing my project and implementing it properly.His encouragement during the problems faced in the project has given me the strength to continue it to completion.

Further I would like to thank Mr. Kunal,Technical Assistant,Mechanical engineering dept.,for helping me out with the project with his expertise. Also I thank various other persons who have helped me out with this project.

SHAIK ZUNEID ALAM

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ABSTRACT

A solar cloth dryer was made with the help of available materials.Its efficiency was investigated with respect to how fast it was able to dry up the clothes.Hence a set of experiments were performed to determine the worthiness of this solar dryer.The experiments showed that the dryer works fine as per its objectives.The main advantage of this dryer is that it can work all round the year,with a built-in auxiliary heating system.Also,with no moving parts,it consumes less power than conventional dryers in washing machines.It can easily be built with commonly available materials.

Chapter-1

INTRODUCTION

1.1 General

Renewable energy technology bridges the gap between mounting global energy demand and dwindling supply of finite conventional energy sources.The two factors that must be constantly looked into are the efficiency and economics of installing such an application.

Solar technologies are broadly characterized as either passive solar or active solardepending on the way they capture, convert and distribute sunlight. Active solar techniques include the use of photovoltaic panels, solar thermal collectors, with electrical or mechanical equipment, to convert sunlight into useful outputs. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air. The solar radiation potential of India is 4.7 $kW/m^2/day$. Utilization of solar energy is of great importance to India since it lies in a temperature climate of the region of the world where sun light is abundant for a major part of the year.

In various forms of technology,solar thermal applications have been in energy conversion devices,central heating,cooking,drying and even refrigeration.Drying is a vital operation in any industrial process and daily needs,requiring substantial conventional energy.Drying of clothes is a daily operation.However,in situations and places like hospitals and hotels,this process does not work effectively viz. if there is considerable humidity,less sunlight,rainy season,drying of clothes on a large scale when quick drying is needed.Hence,conventional dryers prove to be energy-consuming and less efficient in such situations. In the drying of washing machines,centrifugal forces are taken into account.There is one drawback in this method of drying as the water still remains in the capillaries of the clothes and hence take a longer time to dry out in short time. The current project is an attempt to fabricate and develop a dryer based on solar energy which can redress these problems effectively,and thus prove to be an efficient alternative form of a dryer.

Chapter-2

SOLAR ENERGY AND ITS APPLICATIONS

2.1 General

Solar energy has the greatest potential of all the sources of renewable energy and if only a small amount of this form of energy is used,it will be one of most important supplies of energy specially when other sources in the country have depleted.

Energy comes to the earth from the sun.this energy keeps the temperature of the earth above that in colder space,causes current in the atmosphere and in the ocean,causes the water-cycle and generate photosynthesis in plants.

The solar power where sun hits atmosphere is 10^{17} watts, whereas the solar power on earth's surface is 10^{16} watts. The total world-wide power demand of all needs of civilization is 10^{13} watts. Therefore, the sun gives us 1000 times more power than we need. If we can use 5% of this energy, it will be 50 times what the world will require. The energy radiated by the sun on a bright sunny day is approximately 1 kW/m^2, attempts have been made to make use of this energy in raising steam which may be used in driving the prime movers for the purpose of generation of electrical energy. However on account of large space required, uncertainty of availability of energy at constant rate, due to clouds, winds, haze etc., there is limited application of this source in the generation of electric power. Now-a-days the drawbacks as pointed out that energy cannot be stored and it is a dilute form of energy, are out dated arguments, since the energy can be stored by producing hydrogen, or by storing in other mechanical or electrical devices, or it can be stored in containers of chemicals called eutectric or phase changing salts. These salts which store large quantities of heat in a relatively small volume, melt when they are heated and release heat later as they cool and crystallize. The energy can be concreted in solar furnaces of 5000^o C. The facts speak in favour of solar energy, as we have seen in analysis of commercial energy sources, that world's reserves of coal, oil and gas will be exhausted within a few decades. Nuclear energy involve considerable hazards and nuclear fusion has not yet overcome all the problems of even fundamental research, compared with these technologies, the feasibility of which is still uncertain and contested, the technical utilization of solar energy can prove useful.Utilization of solar energy is of great importance to India since it lies in a temperature climate of the region of the world where sun light is abundant for a major part of the year.

2.2 Applications of solar technology

Solar energy refers primarily to the use of solar radiation for practical ends. All other renewable energies other than geothermal and tidal derive their energy from the sun.

Solar technologies are broadly characterized as either passive or active depending on the way they capture, convert and distribute sunlight. Active solar techniques use photovoltaic panels, pumps, and fans to convert sunlight into useful outputs. Passive solar techniques include selecting materials with favorable thermal properties, designing spaces that naturally circulate air, and referencing the position of a building to the Sun. Active solar technologies increase the supply of energy and are considered supply side technologies, while passive solar technologies reduce the need for alternate resources and are generally considered demand side technologies.

The applications of solar energy which are enjoying most success to-day are:

(1) Heating and cooling of residential building.
(2) Solar water heating.
(3) Solar drying of agricultural and animal products.
(4) Solar distillation on a small community scale.
(5) Salt production by evaporation of seawater or inland brines.
(6) Solar cookers.
(7) Solar engines for water pumping.
(8) Food refrigeration.
(9) Bio conversion and wind energy, which are indirect source of solar energy.
(10) Solar furnaces.

(11) Solar electric power generation by -

(i) Solar ponds.

(ii) Steam generators heated by rotating reflectors (heliostat mirrors), or by tower concept.

(iii) Reflectors with lenses and pipes for fluid circulation (cylindrical parabolic reflectors).

(12) Solar photovoltaic cells, which can be used for conversion of solar energy directly into electricity or for water pumping in rural agricultural purposes.

The heat from solar collectors is directly used for warming the living spaces of a building in conventional ways e.g., through radiators and hot air registers. When the building does not require heat, the warmed air or liquid from the collector can be moved to a heat storage container. In the case of air, the storage is often a pile of rocks or some other heat-holding material, in the case of liquid, it is usually a large, well insulated tank of water, which has considerable heat capacity. Heat is also stored in containers of chemicals called *eutectic* or *phase changing salts.* These salts, which store large quantities of heat in a relatively small volume, melt when they are heated and release heat later as they cool and crystallize. When the building needs heat, the air or water from its heating system passes through the storage is warmed, and is then fed through the conventional heaters to warm the space. For sunless days or cloudy days, an auxiliary system as a back-up, is always required. The same is true for solar cooling systems. In the United States, heating, ventilation and air conditioning (HVAC) systems account for 30% (4.65 EJ) of the energy used in commercial buildings and nearly 50% (10.1 EJ) of the energy used in residential buildings. Solar heating, cooling and ventilation technologies can be used to offset a portion of this energy.

Thermal mass is any material that can be used to store heat—heat from the Sun in the case of solar energy. Common thermal mass materials include stone, cement and water. Historically they have been used in arid climates or warm temperate regions to keep buildings cool by absorbing solar energy during the day and radiating stored heat to the cooler atmosphere at night. However they can be used in cold temperate areas to maintain warmth as well. The size and placement of thermal mass depend on several factors such as climate, daylighting and shading conditions. When properly incorporated, thermal mass maintains space temperatures in a comfortable range and reduces the need for auxiliary heating and cooling equipment.

A ***solar chimney*** (or thermal chimney, in this context) is a passive solar ventilation system composed of a vertical shaft connecting the interior and exterior of a building. As the chimney warms, the air inside is heated causing an updraft that pulls air through the building. Performance can be improved by using glazing and thermal mass materials in a way that mimics greenhouses.

Deciduous trees and plants have been promoted as a means of controlling solar heating and cooling. When planted on the southern side of a building, their leaves provide shade during the summer, while the bare limbs allow light to pass during the winter. Since bare, leafless trees shade 1/3 to 1/2 of incident solar radiation, there is a balance between the benefits of summer shading and the corresponding loss of winter heating. In climates with significant heating loads, deciduous trees should not be planted on the southern side of a building because they will interfere with winter solar availability. They can, however, be used on the east and west sides to provide a degree of summer shading without appreciably affecting winter solar gain.

Solar energy units for heating domestic water are commercially available and are used by millions of people in various parts of the world, for example in Australia, Israel, Japan etc. A solar water heater commonly comprises a blackened flat plate metal collector with an associated metal tubing, facing the general direction of the sun. The collector is provided with a transparent glass cover and a layer of thermal insulation beneath the plate. The collector tubing is connected by a pipe to an insulated tank that stores hot water during non-sunny periods. The collector absorbs solar radiation and by transfer of resulting heat to the water circulating through the tubing by gravity or by a pump, hot water is supplied to the storage tank. Solar hot water systems use sunlight to heat water. In low geographical latitudes (below 40 degrees) from 60 to 70% of the domestic hot water use with temperatures up to 60 °C can be provided by solar heating systems. The most common types of solar water heaters are evacuated tube collectors (44%) and glazed flat plate collectors (34%) generally used for domestic hot water; and unglazed plastic collectors (21%) used mainly to heat swimming pools.

As of 2007, the total installed capacity of solar hot water systems is approximately 154 GW. China is the world leader in their deployment with 70 GW installed as of 2006 and a long term goal of 210 GW by 2020. Israel and Cyprus are the per capita leaders in the use of solar hot water systems with over 90% of homes using them. In the United States, Canada and

Australia heating swimming pools is the dominant application of solar hot water with an installed capacity of 18 GW as of 2005.

Solar water heating systems for domestic, industrial and commercial applications are at present available. In commercial establishments, there is great potential especially in hotels, hospitals, guest houses, tourist bungalows, canteen etc. For industrial applications solar water heating system can meet the low and medium temperature process heat requirements hot water upto 90^{o}C, hot air upto 110^{o}C and low pressure steam upto 140^{o}C. These are specially useful in engineering, textile, chemicals, pharmaceutical, food processing, sugar, dairy and other industries. Hot water systems have relevance for many agricultural and village industries, such as for handloom fabrics, seri-culture, leather tanning and hand made paper.

S***olar distillation*** admits solar radiation through a transparent cover to a shallow, covered brine basin; water evaporates from the brine and the vapour condenses on the covers which are so arranged that the condensate flows there-from into collection troughs and hence into a product-water storage. In arid, semi arid, or coastal areas, there is abundant sun light that can be used for convering brackish or saline water into potable distilled water.

A traditional and wide-spread use of solar energy is for drying particularly of agricultural products. This is a process of substantial economic significance in many areas. The process is of special interest in the case of soft fruits; these are particularly vulnerable to attack by insects, as the sugar concentration increases during drying. Fruit dryer in which fruit is placed, in casrefully designed racks to provide controlled exposure to solar radiation often improves quality and saves considerable time. A simple cabinet dryer consists of a box, insulated at the base, painted black on the inside and covered with an inclined transparent sheet of glass. Ventilation holes are provided at the base and at the top of the sides of the box to facilitate a flow of air over the drying material, which is placed on perforated trays in the interior of the cabinet base.

Large drying systems like grain, paddy, maize, cash crops like ginger, cashew, pepperm etc., spray drying of milk; timber and veneer drying; tobacco curing; fish and fruit drying, etc have also been developed.

Solar refrigeration is intended for food preservation (or storage of biological and medical materials) and deserves top-priority in country like India. Solar air conditioning can be utilized for space cooling. Solar assisted heat pumps would provide both cooling and heating. Active solar cooling wherein solar thermal collectors provide thermal energy to drive thermally-driven chillers (usually ADsorption or ABsorption chillers).The solar thermal energy system can be also used to produce hot water.

There are multiple alternatives to compressor-based chillers that can reduce energy consumption by 80%, with less noise and vibration. Solar thermal energy can be used to efficiently cool in the summer, and also heat domestic hot water, and the building in the winter. The Audubon Environmental Center in Los Angeles is one example among many). Single, double or triple iterative absorption cooling cycles are used in different solar-thermal-cooling system designs. The more cycles, the more efficient they are.

In the late 1800s, the most common phase change refrigerant material for absorption cooling was a solution of ammonia and water. Today, the combination of lithium and bromide is also in common use. One end of the system of expansion / condensation pipes is heated, and the other end gets cold enough to make ice. Originally, natural gas was used as a heat source in the late 1800s. Today, propane is used in recreational vehicle absorption chiller refrigerators. Innovative hot water solar thermal energy collectors can also be used as the modern "free energy" heat source.

Efficient absorption chillers require water of at least 190 °F (88 °C). Common, inexpensive flat-plate solar thermal collectors only produce about 160 °F (71 °C) water, but several successful commercial projects in the US, Asia and Europe have shown that flat plate solar collectors specially developed for temperatures over 200 °F (featuring double glazing, increased backside insulation, etc.) can be effective and cost efficient. Evacuated-tube solar panels can be used as well. Concentrating solar collectors required for absorption chillers are less effective in hot humid, cloudy environments, especially where the overnight low temperature and relative humidity are uncomfortably high. Where water can be heated well above 190 °F (88+ °C), it can be stored and used when the sun is not shining.

For 150 years, absorption chillers have been used to make ice (before the electric light bulb was invented). This ice can be stored and used as an "ice battery" for cooling when the sun is not shining, as it was in the 1995 Hotel New Otani in Tokyo Japan. Mathematical models are available in the public domain for ice-based thermal energy storage performance calculations.

The ISAAC Solar Icemaker is an intermittent solar ammonia-water absorption cycle. The ISAAC uses a parabolic trough solar collector and a compact and efficient design to produce ice with no fuel or electric input, and with no moving parts.

Cold storages are very important for preservation and conservation of food articles.

There are two methods of solar refrigeration.

(a)Vapour absorption refrigeration system that utilizes low grade thermal energy obtained from flat plate collectors with a little modification.

(b) Concentrating (focusing) collectors to supply heat at a higher temperature to a heat engine which then drives the compressor of a conventional refrigerator.

Solar refrigeration with an absorption system is a better way of direct utilization of energy. The vapour absorpton system replacing the compressor by a generator absorber assembly can work with wide range of absorbents and refrigerants. In absorption system motive power required is very small C.O.P. of the system is low.

Electricity from Solar Energy-Electricity can be produced from the solar energy by photo volaic solar cells, which convert the solar energy to electricity. The most significant applications of photo voltaic cell in India, are the energisation of pump sets for irrigation, drinking water supply and rural electrification covering street lights, community TV sets, medical refrigerators and other small power loads. Electricity is directly generated by utilizing solar energy by the photo voltaic process. When photons from the sun are absorbed in a semi-conductor, they create free electrons with higher energies than the electrons are created, there must be an electric field to induce these higher energy electrons to flow out of the semiconductor to do useful work. The electric field in most solar cells is provided by a junction of materials which have different electrical electrical properties. The photovoltaic effect can be described easily which for *p-n* junction in semi-conductor materials of solar cells which are silicon, cadmium, sulphide/copper sulphide, Gallium Arsenite etc.

In a ***solar thermal power production*** system the energy is first collected by using a solar pond, a flat plate collector, focusing collector or heliostats (turnable mirrors). This energy is used to increase the internal energy or temperature of a fluid. This fluid may be directly used in any of the common or known cycles such as Rankine, or through a heat exchanger to heat a secondary fluid (working fluid) which is being used in the cycle to produce mechanical power from which electrical power can be produced easily.

Solar thermal power cycles can be broadly classified as low medium and high temperature cycles. Low temperature cycles generally use flat plate collectors or solar pond, maximum temperatures are limited to above 90 to 100^{o}C. Medium temperature cycles work at maximum temperatures ranging from 150 to 300^{o}C, using concentration or focusing collectors. High temperature cycles work at maximum temperatures above 300 ^{o}C.

In solar tower concentration system (Tower power concept), the incoming solar radiation is focused to a central receiver or a boiler mounted on a tall tower using thousands of plane reflectors which are steerable about two axes and are called heliostats. Sunlight can be converted into electricity using photovoltaics (PV), concentrating solar power (CSP), and various experimental technologies. PV has mainly been used to power small and medium-sized applications, from the calculator powered by a single solar cell to off-grid homes powered by a photovoltaic array. For large-scale generation, CSP plants like SEGS have been the norm but recently multi-megawatt PV plants are becoming common. Completed in 2007, the 14 MW power station in Clark County, Nevada and the 20 MW site in Beneixama, Spain are characteristic of the trend toward larger photovoltaic power stations in the US and Europe. As an intermittent power source, solar power requires a backup supply, which can partially be complemented with wind power. Local backup usually is done with batteries, while utilities normally use pumped-hydro storage. The Institute for Solar Energy Supply Technology of the University of Kassel pilot-tested a combined power plant linking solar, wind, biogas and hydrostorage to provide load-following power around the clock, entirely from renewable sources.

Result to-date show solar energy to be quite competitive with other sources of energy, if the solar tower plant size is about 100-200 Mwe, with 3-6 hours thermal storage.

Over the last few years, few experiment power plants have been built or under construction in U.S.A, France, Italy and Japan.

***Solar Vehicles**:* Development of a solar powered car has been an engineering goal since the 1980s. The World Solar Challenge is a biannual solar-powered car race, where teams from universities and enterprises compete over 3,021 kilometres (1,877 mi) across central Australia from Darwin to Adelaide. In 1987, when it was founded, the winner's average speed was 67 kilometres per hour (42 mph) and by 2007 the winner's average speed had improved to 90.87 kilometres per hour (56.46 mph). The North American Solar Challenge and the planned South African Solar Challenge are comparable competitions that reflect an international interest in the engineering and development of solar powered vehicles.

Some vehicles use solar panels for auxiliary power, such as for air conditioning, to keep the interior cool, thus reducing fuel consumption.

In 1975, the first practical solar boat was constructed in England. By 1995, passenger boats incorporating PV panels began appearing and are now used extensively. In 1996, Kenichi Horie made the first solar powered crossing of the Pacific Ocean, and the *sun21* catamaran made the first solar powered crossing of the Atlantic Ocean in the winter of 2006–2007. There are plans to circumnavigate the globe in 2010.

In 1974, the unmanned *Sunrise II* plane made the first solar flight. On 29 April 1979, the *Solar Riser* made the first flight in a solar powered, fully controlled, man carrying flying machine, reaching an altitude of 40 feet (12 m). In 1980, the *Gossamer Penguin* made the first piloted flights powered solely by photovoltaics. This was quickly followed by the *Solar Challenger* which crossed the English Channel in July 1981. In 1990 Eric Raymond in 21 hops flew from California to North Carolina using solar power. Developments then turned back to unmanned aerial vehicles (UAV) with the *Pathfinder* (1997) and subsequent designs, culminating in the *Helios* which set the altitude record for a non-rocket-propelled aircraft at 29,524 metres (96,860 ft) in 2001. The *Zephyr*, developed by BAE Systems, is the latest in a line of record-breaking solar aircraft, making a 54-hour flight in 2007, and month-long flights are envisioned by 2010.

A solar balloon is a black balloon that is filled with ordinary air. As sunlight shines on the balloon, the air inside is heated and expands causing an upward buoyancy force, much like an artificially heated hot air balloon. Some solar balloons are large enough for human flight, but usage is generally limited to the toy market as the surface-area to payload-weight ratio is relatively high.

Solar sails are a proposed form of spacecraft propulsion using large membrane mirrors to exploit radiation pressure from the Sun. Unlike rockets, solar sails require no fuel. Although the thrust is small compared to rockets, it continues as long as the Sun shines onto the deployed sail and in the vacuum of space significant speeds can eventually be achieved.

The High-altitude airship (HAA) is an unmanned, long-duration, lighter-than-air vehicle using helium gas for lift, and thin-film solar cells for power. The United States Department of Defense Missile Defense Agency has contracted Lockheed Martin to construct it to enhance the Ballistic Missile Defense System (BMDS). Airships have some advantages for solar-powered flight: they do not require power to remain aloft, and an airship's envelope presents a large area to the Sun.

Solar Pond*:* A solar pond is large-scale solar thermal energy collector with integral heat storage for supplying thermal energy. A solar pond can be used for various applications, such as process heating, desalination, refrigeration, drying and solar power generation. A solar pond is simply a pool of saltwater which collects and stores solar thermal energy. The saltwater naturally forms a vertical salinitygradient also known as a "halocline", in which low-salinity water floats on top of high-salinity water. The layers of salt solutions increase in concentration (and therefore density) with depth. Below a certain depth, the solution has a uniformly high salt concentration.

There are 3 distinct layers of water in the pond:

- The top layer, which has a low salt content.
- An intermediate insulating layer with a salt gradient, which establishes a density gradient that prevents heat exchange by naturalconvection.

- The bottom layer, which has a high salt content.

If the water is relatively translucent, and the pond's bottom has high optical absorption, then nearly all of the incident solar radiation (sunlight) will go into heating the bottom layer.

When solar energy is absorbed in the water, its temperature increases, causing thermal expansion and reduced density. If the water were fresh, the low-density warm water would float to the surface, causing a convection current. The temperature gradient alone causes a density gradient that *decreases* with depth. However the salinity gradient forms a density gradient that *increases* with depth, and this counteracts the temperature gradient, thus preventing heat in the lower layers from moving upwards by convection and leaving the pond. This means that the temperature at the bottom of the pond will rise to over 90 °C while the temperature at the top layer will not vary as such.The power can be generated using the Stirling Cycle.

Chapter-3

SOLAR ENERGY COLLECTORS

3.1 General

A solar collector is a device for extracting the energy of the sun directly into a more usable or storable form. The energy in sunlight is in the form of electromagnetic radiation from the infrared (long) to the ultraviolet (short) wavelengths. The solar energy striking the earth's surface at any one time depends on weather conditions, as well as location and orientation of the surface, but overall, it averages about 1000 watts per square meter under clear skies with the surface directly perpendicular to the sun's rays.

3.2 Physical Principles of the Conversion of Solar Radiation into Heat:

The fundamental process now in general use for heat conversion is the *green house effect*. The name come from its first use in green houses, in which it is possible to grow exotic plants in cold climates through better utilization of the available sunlight.

Most of the energy we receive from the sun comes in the form of light, a shortwave radiation, not all of which is visible to the human eye. When this radiation strikes a solid or liquid, it is absorbed and transformed into heat energy; the material becomes warm and stores the heat, conducts it to surrounding materials (air water, other solids or liquids) or reradiates it to other materials of lower temperature. This reradiation is a long wave radiation.

Visible sunlight is absorbed on the ground, at a temperature of $20^{o}C$, for example emits infra-red light at a wavelength of about $10\mu m$, but (CO_2 does not absorbs the incoming sunlight which has a shorter wavelength).

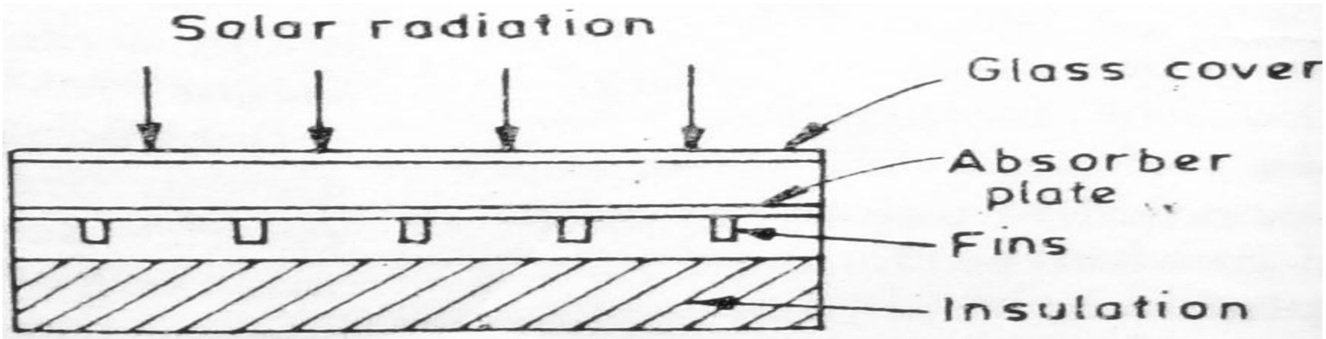

Fig. 3.1 liquid flat plat collector (source: from the book "non-conventional sources of energy" by G D Rai,Khanna publishers)

Hence the green house effect brings about an accumulation of energy of the ground.

Glass easily transmits short –wavelength radiation, which means that it poses little interference to incoming solar energy, but it is a very poor through transmitter of long-wave radiation. Once the sun's energy has passed through the glass windows and has been absorbed by some material inside, the heat will not be reradiated back outside. Glass therefore, act as a heat trap, a phenomenon which has been recognized for sometime in the construction of green houses which can get quite warm on sunny days, even in the middle of winter; this can came to be known in fact, as 'green house effect'. Solar collectors for home heating usually called flat plate collectors, almost have one or more glass covers, although various plastic and other transparent materials are often used instead of glass. Rate but also the highest emission coefficient for all wavelengths of light. Emission increases with temperature, following T^4 law. The re-emitted light if so progressively shorter wavelength and greater energy as the temperature of black body increases.

The sun emits radiation like a "black body" whose surface temperature is about 5700^{o}C, this corresponds to maximum emission of 0.5μm. A black body at a room temperature emits radiation with a maximum at about 10μm, which is within the spectrum of invisible of infra-red light. The ordinary glass plate fixed above the black plate in a green house has a spectral absorption which can be seen in Fig.3.2.3. The profile of plastic is similar. Thus glass which is relatively transparent for visible light is absorbent for the infra-red light emitted by the black plate when it evacuates its thermal energy. The infra-red light absorbed by the glass is remitted in all directions, half of it is emitted to the outside and lost, the other half re-emitted towards the black plate which absorbs it again. More and more heat is accumulated in the way in the black plate, whose temperature thus increases. Equilibrium is reached when the energy gain by absorption of visible light is exactly balanced by the loss of energy through infra-red emission of the glass plate. With rising temperature, the wavelength of the infra-red emission becomes shorter. At 200^{o}C (473^{o}K) the maximum radiation is emitted at about 6μm, at which wavelength, glass is partially transparent for infra-red light.

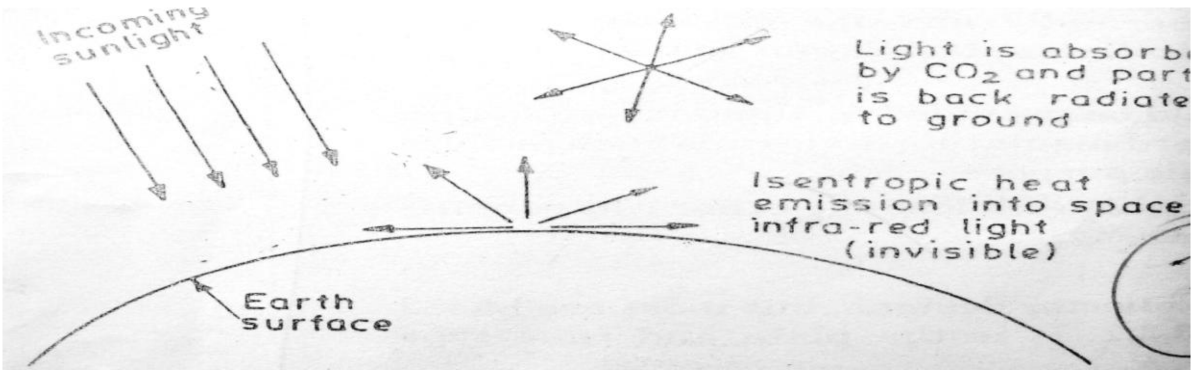

Fig. 3.2 greenhouse effect **(source: from the book "non-conventional sources of energy" by G D Rai,Khanna publishers)**

It follows that an efficient green house effect is possible only below 500^{o}C. However, unless concentration of sunlight is combined with the green house effect, the equilibrium temperature achieved are much lower because, practice, the equilibrium temperature is further reduced by heat losses from the black plate due to thermal conductivity and air convection.

Where temperature below about 90^{o}C are adequate, as they are for space and service water heating flat plate collectors, which are of the non-concentrating type, are particularly convenient. They are made in rectangular panels, from about 1.7 to 2.9 sq. m, in area, and are relatively simple to construct and erect. Flat plates can collect and absorb both direct and diffuse solar radiation, they are consequently partially effective even on cloudy days when there is no direct radiation.

Flat-plate solar collectors may be divided into two main classification based on the type of heat transfer fluid used.Liquid heating collectors are used for heating water and non-freezing aqueous solutions and occasionally for non-aqeous heat transfer fluids. Air or gas heating collectors are employed as solar air heaters.

The principal difference between the two types is the design of the passages for the heat for the transfer fluid.

The majority of the flat-plate collector have five main components as follows:

(i) A transparent cover which may be one or more sheets of glass or radiation transmitting plastic film or sheet.

(ii) Tubes, fins, passages or channels are integral with the collector absorber plate or connected to it, which carry the water, air or other fluid.

(iii) The absorber plate, normally metallic or with a black, surface, although a wide variety of other materials can be used with air heaters.

(iv) Insulation, which should be provided at the back and sides to minimize the heat losses. Standard insulating materials such as fibre glass or styro-foam are used for this purpose.

(v) The casing or container which enclose the other components and protects them from the weather.

The solar heating system consists of the collector described above; a heat transfer circuit that includes the fluid and the means to circulate it; and a storage system including a heat exchanger (if the fluid circulating through the collector is not the same liquid being used to heat the object of the system). The system may or may not include secondary distribution of heat among different storage reservoirs or users of the heat. The system can be used in a variety of ways, including warming domestic hot water, heating swimming pools, heating water for a radiator or floor-coil heating circuit, heating an industrial dryer, or providing input energy for a cooling system, among others. The heat is normally stored in carparks. Heat storage is usually intended to cover a day or two's requirements, but other concepts exist including seasonal storage (where summer solar energy is used for winter heating by just raising the temperature by a few degrees of several million litres of water (numerous pilot housing projects in Germany and elsewhere use this concept).solar collectors are a good way to collect energy.

3.3 System types

For solar heating of domestic hot water, two common system types are thermosyphon and pumped. In the thermosyphon system, a storage tank is placed above the collector. As the water in the collector is heated, it will rise and naturally start to circulate around the tank. This draws in colder water from the bottom of the tank. This system is self-regulating and requires no moving parts or external energy, so is very attractive. Its main drawback is the need for the tank to be placed at a level higher than the collector, which may prove to be physically difficult. A pumped system uses a pump to circulate the water, so the tank can be positioned independently of the collector location. This system requires external energy to run the pump (though this can be solar, since the water should only be circulated when there is incident sunlight). It also requires control electronics to measure the temperature gradient across the collector and modulate the pump accordingly. Systems using solar electric pumping and controls are known as zero carbon solar while those using mains electricity are known as low carbon, since they typically have a 10-20% carbon drawback.

3.4 Placement

Solar collectors can be mounted on a roof but need to face the sun, so a north-facing roof in the southern hemisphere, and a south-facing roof in the northern hemisphere is ideal. Collectors are usually also angled to suit the latitude of the location. Where sunshine is readily available, a 2 to 10 square metre array will provide all the hot water heating required for a typical family house. Such systems are a key feature of sustainable housing, since water and space heating is usually the largest single consumer of energy in households.

3.5 Solar thermal collectors

A solar thermal collector that stores heat energy is called a "batch" type system. Other types of solar thermal collectors do not store energy but instead use fluid circulation (usually water or an antifreeze solution) to transfer the heat for direct use or storage in an insulated reservoir. Water/glycol has a high thermal capacity and is therefore convenient to handle. The direct radiation is captured using a dark colored surface which absorbs the radiation as heat and conducts it to the transfer fluid. Metal makes a good thermal conductor, especially copper and aluminium. In high performance collectors, a "selective surface" is used in which the collector surface is coated with a material having properties of high-absorption and low-emissivity. The selective surface reduces heat-loss caused by infrared radiant emission from the collector to ambient. Another method of reducing radiant heat-loss employs a transparent window such as clear UV stabilized plastic or Low-emissivity glass plate. Again, Low-E materials are the most effective, particularly the type optimized for solar gain. Borosilicate glass or "Pyrex" (tm) has low-emissivity properties, which may be useful, particularly for solar cooking applications.

As it heats up, thermal losses from the collector itself will reduce its efficiency, resulting in increased radiation, primarily infrared. This is countered in two ways. First, a glass plate is placed above the collector plate which will trap the radiated heat within the airspace below it. This exploits the so-called greenhouse effect, which is in this case a property of the glass: it readily transmits solar radiation in the visible and ultraviolet spectrum, but does not transmit the lower frequency infrared re-radiation very well.

The glass plate also traps air in the space, thus reducing heat losses by convection. The collector housing is also insulated below and laterally to reduce its heat loss.

The second way efficiency is improved is by cooling the absorber plate. This is done by ensuring that the coldest available heat transfer fluid is circulated through the absorber, and with a sufficient flow rate. The fluid carries away the absorbed heat, thus cooling the absorber. The warmed fluid leaving the collector is either directly stored, or else passes through a heat exchanger to warm another tank of water, or is used to heat a building directly. The temperature differential across an efficient solar collector is usually only 10 or 20°C. While a large differential may seem impressive, it is in fact an indication of a less efficient design.

3.5.1 A typical liquid collector

It is the plate and tube type collector. It basically consists of a flat surface with high absorptivity for solar radiation, called the absorbing surface.

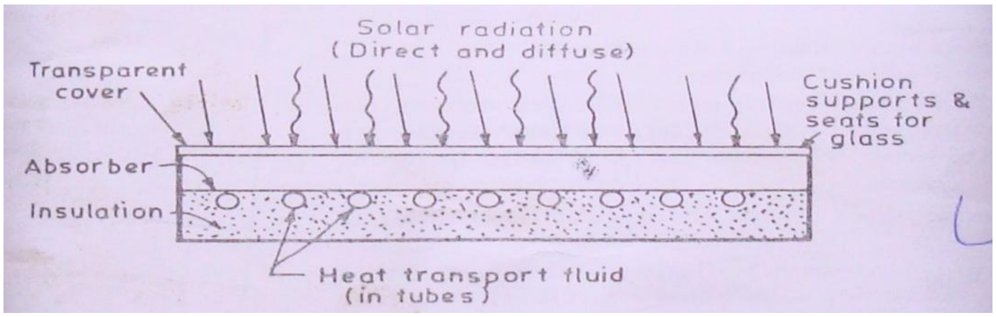

Fig. 3.3 liquid collector(source: from the book "non-conventional sources of energy" by G D Rai,Khanna publishers)

Typically a metal plate, usually of copper, steel or aluminium material with tubing of copper in thermal contact with the plates, are the most commonly used materials. The absorber plate is usually made from a metal sheet 1 to 2 mm in thickness, while the tubes, which are also of metal, range in diameter from 1 to 1.5 cm. They are soldered, brazed or clamped to the bottom (in some cases, to the top) of the absorber plate with the pitch ranging from 5 to 15 cm. In some designs, the tubes are also in line and integral with the absorber plate. For the absorber plate corrugated galvanized sheet is a material widely available throughout the world.

The use of conventional standard panel radiators is one of the simplest practical applications.The "tube in strip" or roll bond design, in which the tubes are formed in the sheet, ensuring a good thermal bond between the sheet and the tube.

Heat is transferred from the absorber plate to a point of use by circulation of fluid (usually water) across the solar heated surface. Thermal insuklation of 5 to 10 cm thickness is usually placed behind the absorber plate to prevent the heat losses from the rear surface. Insulation materials is generally mineral wool or glass wool or fiberglass as stated above.

The front covers are generally glass (may be one or more) that is transparent to in-coming solar radiation and opaque to the infra-red re-radiation from the absorber. The glass covers act as a convection shield to reduce the losses from the absorber plate beneath. Glass is generally used for the transparent covers but certain plastic films may be satisfactory. Glass is the most favourable material. Thickness of 3 and 4 mm are commonly used. The usual practice is to have 1 or 2 covers with a specific ranging from 1.5 to 3 cm.

Advantages of second glass which is added above the first one are:

Losses due to air convection are further reduced. This is important in windy areas.Radiation losses in the infra-red spectrum are reduced by a further 25%, because half of the 50% which is emitted outwards from the first glass plate is back radiated. It is not worthwhile to use more than two glass plates. This is due to the fact that each plate reflects about 15% of the incoming sunlight.

As we know that main purpose of the transparent cover of the flat-plate collector is to decrease heat loss without significantly reducing the incoming solar radiation. In the first place, the relatively still (or stagnant) air space between the cover and the absorber plate largely prevents loss of heat from the plate by convection.

Furthermore, if the cover is made of glass, it permits the passage of solar radiations with wavelengths less than 2 micrometers (μm) but it is largely opaque to the longer wavelength thermal infra-red. As a result, heat is trapped in the air space between the cover and the absorber plate in a manner similar to green house. The effect is to reduce the loss of heat from the absorber. However, since the enclosed air is inevitably warmer than the ambient air, there is some loss of heat to the surroundings from the top of the cover by convection, conduction and radiation. The rate of heat loss increases as the temperature of the air space rises; as will be seen shortly, this affects the overall efficiency of the solar collector.

A certain proportion of the incident solar radiation is lost by absorption in the glass cover plates, but the loss can be kept small by using a clear ("water white") glass with a low iron content. A much larger loss occurs as a result of partial reflection. Two glass plates may reflect some 15 percent of the solar radiation coming from a perpendicular direction. The reflection loss increases as the direction of incidence departs from the perpendicular. The reflection of glass covers may be reduced by coating with thin films of certain substances (e.g., magnesium fluoride) or by gentle etching with a solution of hydrofluoric acid. Such antireflective coatings add to the cost of the collectors but make them more efficient.

3.5.2 Typical Air Collectors or Solar Air Heaters:

The flat-plate collector where an air stream is heated by the back side of the collector plate. Fins attached to the plate increase the contact surface. The back side of the collector is heavily insulated with mineral wool or some other material. The most favourable orientation, of a collector, for heating only is facing due south at an inclination angle to the horizontal equal to the latitude plus 15^o.

Air has been used so far to a lesser extent as the heat-transport medium in solar collectors, but it may have some advantages over water. To decrease the power required to pump the necessary volume of air through tubes, wider flow channels are used. For example, the air may be passed through a space between the absorber plate and insulator with baffles arranged to provide a long (zig-zag) flow path.

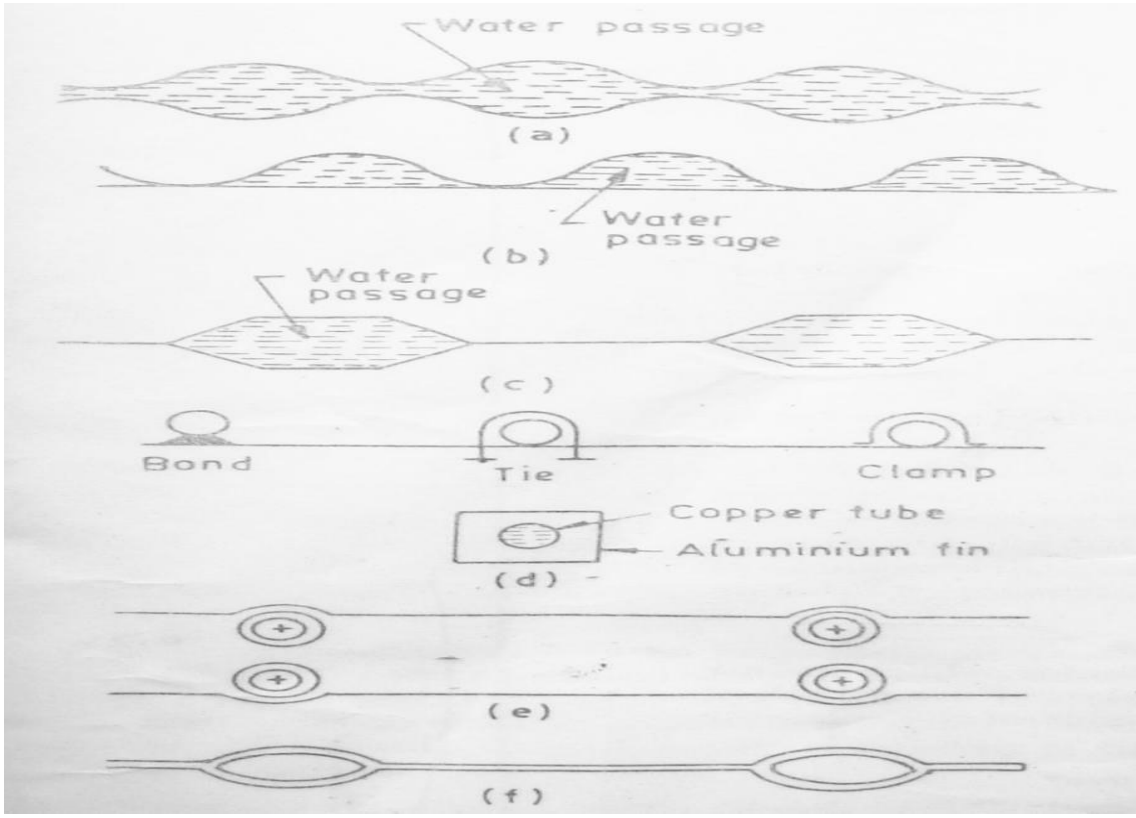

Fig. 3.4 solar collector configurations (**source: from the book "non-conventional sources of energy" by G D Rai,Khanna publishers)**

The use of air as the heat-transport fluid eliminates both freezing and corrosion problems, and small air leaks are of less concern than water leaks. Moreover, the heated air can be used directly (or by way of heat storage) for space heating. On the other hand, larger duct sizes and higher flow rates, with increased pumping power, are required for air than when water is the heat transport medium. Another drawback is that transfer of heat from air to water in a hot water supply system is inefficient.

But solar air heater has an important place among solar heat collectors. It can be used as subsystems in many systems meant for the utilization of solar energy. Possible applications of solar air heraters are drying or curing of agricultural products, space heating for comfort, regeneration of dehumidifying agents, seasoning of timber, curing of industrial products such as plastics.

Air can be passed in contact in contact with black solar absorbing surface such as finned plates or ducts as mentioned above, corrugated or roughened plates of various materials, several layer of metal screening and overlapped glass plates. Flow may be straight through, surpentine, above or below or on both sides of the absorber plate, or through a porous absorber material.

Basically air heaters are classified in the following two categories.

(1) The first type has a non-porous absorber in which the air stream does not flow through the absorber plate. Air may flow above and or behind the absorber plate.
(2) The second type has a porous absorber that includes slit and expanded metal, transpired honey comb and over-lapped glass plate absorber.
(3) The overlapped glass plate air heater can be considered as a form of porous matrix, although overall flow direction is along the absorber glass plates instead of being across the matrix. Plate and air stream temperature increase gradually along the collector length and across from top to bottom. Thus thermal losses could be significantly reduced. The pressure drop is also significantly less than the non-porous flat-plate absorber design.

3.5 Applications of Solar Air Heaters.

The solar air heaters, which supply hot air that could be mainly used for the following processes:

(i) Heating buildings
(ii) Drying agricultural produce and lumber.
(iii) Heating grren houses.
(iv) Air conditioning buildings utilizing desiccant beds or a absorption refrigeration process.
(v) Using air heaters as the heat sources for a heat engine such as a Brayton or Stirling cycle.

3.6 Advantages of Flat-plate Collectors

(i) They have the advantages of using both beam and diffuse solar radiation.
(ii) They do not require orientation towards the sun.
(iii) They require little maintenance.

(iv) They are mechanically simpler than the concentrating reflectors, absorbing surfaces and orientation devices of focusing collectors.

Chapter-4

SOLAR DISTILLATION

4.1 General

Decline in drinking water quality is affecting millions in developing countries.Though many remediation technologies are available, for common peopleit's a distinct dream and many options lack appropriateness.Sunlight is the most abundant natural resource in the world. Areas reeling under water stress receive upto 200-300 sunny days a year. Renewably, steam is the purest form of water. Solar Desalination/ Distillation involves heating of raw water, producing steam and condensing steam into drinking water. Dissolved Solids level in Solar Distilled water is less than 3 ppm and Bacteria free. The water is 100% safe, with no taste of hardness.

Solar Desalination is applicable in all areas with 'sunlight" and facing water contaminations from sea water, excess of iron, fluoride, nitrates, arsenic, calcium hardness etc. The temperature developed inside the still is over 850 Cel. During rainy days, the still can be altered for Rain Water collection if needed. Up to 90% of the input water is recovered as distilled water, ecologically sound and no energy costs. Solar distillation is a relatively simple treatment of brackish (i.e. contain dissolved salts) water supplies. Distillation is one of many processes that can be used for water purification and can use any heating source. Solar energy is a low tech option. In this process, water is evaporated, using the energy of the sun then the vapour condenses as pure water.This process removes salts and other impurities. Solar distillation is used to produce drinking water or to produce pure water for lead acid batteries, laboratories, hospitals and in producing commercial products such as rose water. It is recommended that drinking water has 100 to 1000 mg/l of salt to maintain electrolyte levels and for taste. Some saline water may need to be added to the distilled water for acceptable drinking water.

Solar water distillation is a very old technology. An early large-scale solar still was built in 1872 to supply a mining community in Chile with drinking water. It has been used for emergency situations including navy introduction of inflatable stills for life boats.

There are a number of other approaches to desalination, such as photovoltaic powered reverseosmosis, for which small-scale commercially available equipment is available; solar distillation has to be compared with these options to determine its appropriateness to any situation. If treatment of polluted water is required rather than desalination, slow sand filtration is a low cost option.

4.2 Energy requirements for water distillation

The energy required to evaporate water, called the latent heat of vaporisation of water, is 2260 kilojoules per kilogram (kJ/kg). This means that to produce 1 litre (i.e. 1kg as the density of water is 1kg/litre) of pure water by distilling brackish water requires a heat input of 2260kJ. This does not allow for the efficiency of the system sued which will be less than 100%, or for any recovery of latent heat that is rejected when the water vapour is condensed.

It should be noted that, although 2260kJ/kg is required to evaporate water, to pump a kg of water through 20m head requires only 0.2kJ/kg. Distillation is therefore normally considered only where there is no local source of fresh water that can be easily pumped or lifted.

4.3 How a simple solar still works

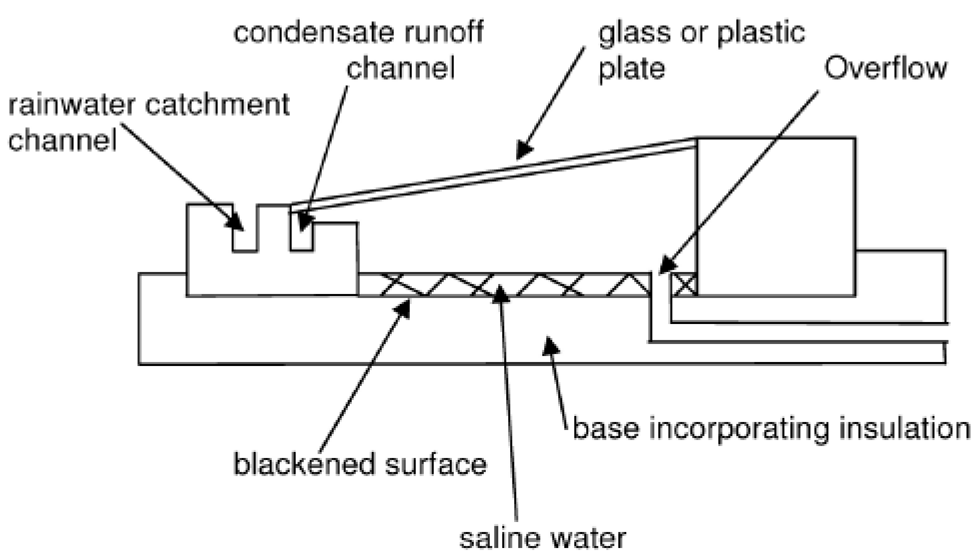

Fig 4.1 Schematic of a single-basin solar still

The main features are the same for all solar stills. The solar radiation is transmitted through the glass or plastic cover and captured by a black surface at the bottom of the still. A shallow layer of water absorbs the heat which then produces vapour within the chamber of the still. This layer should be 20mm deep for best performance.

The vapour condenses on the glass cover, which is at a lower temperature because it is in contact with the ambient air, and runs down into a gutter from where it is fed to a storage tank.

4.4 Design objectives for an efficient solar still

For high efficiency the solar still should maintain

• a high feed (undistilled) water temperature

• a large temperature difference between feed water and condensing surface

• low vapour leakage.

A high feed water temperature can be achieved if:

• a high proportion of incoming radiation is absorbed by the feed water as heat. Hence low absorption glazing and a good radiation absorbing surface are required

• heat losses from the floor and walls are kept low

• the water is shallow so there is not so much to heat.

A large temperature difference can be achieved if:

• the condensing surface absorbs little or none of the incoming radiation

• condensing water dissipates heat which must be removed rapidly from the condensing surface by, for example, a second flow of water or air, or by condensing at night.

4.5 Solar Stills:

Single-basin stills have been much studied and their behaviour is well understood. The efficiency of solar stills which are well-constructed and maintained is about 50% although typical efficiencies can be 25%. Daily output as a function of solar irradiation is greatest in the early evening when the feed water is still hot but when outside temperatures are falling. At very high air temperatures such as over 45ºC, the plate can become too warm and condensation on it can become problematic, leading to loss of efficiency.

Some problems with solar stills which would reduce their efficiency include:-

• Poor fitting and joints, which increase colder air flow from outside into the still

Cracking, breakage or scratches on glass, which reduce solar transmission or let in air

• Growth of algae and deposition of dust, bird droppings, etc. To avoid this the stills need to be cleaned regularly every few days

• Damage over time to the blackened absorbing surface.

• Accumulation of salt on the bottom, which needs to be removed periodically

• The saline water in the still is too deep, or dries out. The depth needs to be maintained at around 20mm .

The cover can be either glass or plastic. Glass is preferable to plastic because most plastic degrades in the long term due to ultra violet light from sunlight and because it is more difficult for water to condense onto it. Tempered low-iron glass is the best material to use because it is highly transparent and not easily damaged (Scharl & Harrs, 1993). However, if this is too expensive or unavailable, normal window glass can be used. This has to be 4mm think or more to reduce breakages. Plastic (such as polyethylene) can be used for short-term use.

Stills with a single sloping cover with the back made from an insulating material do not suffer from a very low angle cover plate at the back reflecting sunlight and thus reducing efficiency.

It is important for greater efficiency that the water condenses on the plate as a film rather than as droplets, which tend to drop back into the saline water. For this reason the plate is set at an angle of 10 to 20^o. The condensate film is then likely to run down the plate and into the run off channel. Brick, sand concrete or waterproofed concrete can be used for the basin of a long-life still if it is to be manufactured on-site, but for factory-manufactured stills, prefabricated ferro-concrete can be used. Moulding of stills from fibreglass was tried in Botswana (Yates, Woto & Tlhage, 1990) but in this case was more expensive than a brick still and more difficult to insulate sufficiently, but has the advantage of the stills being transportable.

By placing a fan in the still it is possible to increase evaporation rates. However, the increase is not large and there is also the extra cost and complication of including and powering a fan in what is essentially quite a simple piece of equipment. Fan assisted solar desalination would only really be useful if a particular level of output is needed but the area occupied by the stills is restricted, as fan assistance can enable the area occupied by a still to be reduced for a given output.

4.6 Types of stills

The Mexican still

In the Mexican still two stills such as the above are fixed together to form a triangular tent shape. The glass plates can be supported from below at the apex where they join, but if they are not and just lean against each other, fixed with sealant, this increases the fragility of the still and limits the area even further of each of the glass plates.

The Brace Research Institute still

This is essentially a still as shown in the above drawing. However the stills are placed next to each other over the width of say 10 metres of the distillation plant. Lengthwise, the unit such as shown is built over a considerable distance, such as 15 metres. Glass plates are placed along the length of the still and simply joined with sealant. Units of this size also have two small weirs lengthwise to encourage saline water to flow along the full length of the still. A project of this type was set up by the Brace Research Institute, McGill University, Canada in Haiti. The scale of the unit requires caretakers to be trained in the maintenance of it, and maintenance requirements are quite considerable.

Multiple-effect basin stills

These have two or more compartments. The condensing surface of the lower compartment is the floor of the upper compartment. The heat given off by the condensing vapour provides energy to vaporize the feed water above. Efficiency is therefore greater than for a single-basin still typically being 35% or more but the cost and complexity are correspondingly higher.

Wick stills

In a wick still, the feed water flows slowly through a porous, radiation-absorbing pad (the wick). Two advantages are claimed over basin stills. First, the wick can be tilted so that the feed water presents a better angle to the sun (reducing reflection and presenting a large effective area). Second, less feed water is in the still at any time and so the water is heated more quicklyand to a higher temperature. Simple wick stills are more efficient than basin stills and some designs are claimed to cost less than a basin still of the same output.

Some designs have been developed which incorporate absorbent or film-type materials to increase the surface area of evaporation.

4.8 Use of Reflector

The inside walls of the still can incorporate a reflective coating, such as aluminium foil, to increase the reflection of heat energy onto the evaporating water. It is not known how far this has helped to improve the efficiency of the still.

4.9 Inverted Absorber Solar Stills

Heat is absorbed from the underside of the still to improve efficiency. This allows

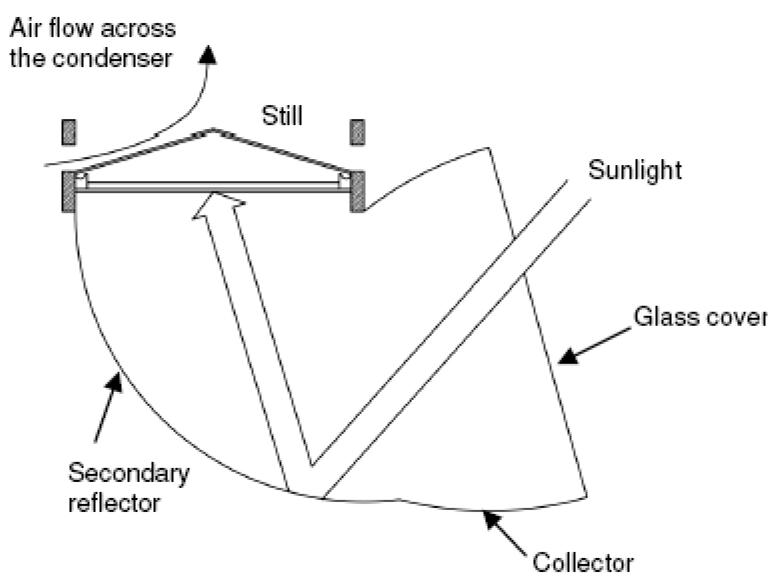

Fig. 4.2 inverted still(source: Solar stills,PRACTICAL ACTION)

condenser plate and the collector plate to be separate. There are several designs of inverted absorber from the fairly simple to more complex designs.

4.10 Spherical Still

In a design developed by the Thermal and Solar Laboratory at Claude Bernard University, Lyons, France, a trough, where the saline water is placed, is positioned in the centre of a hollow transparent plastic sphere. Distillate water condenses on the inside surface of the sphere and is collected by a mechanical windscreen type wiper blade which forces the condensed water to fall to the bottom of the sphere to be collected. There seems to be a small improvement in efficiency compared with a conventional solar still, but the greater cost of this still might cancel out this advantage.

4.11 Inclined Stills

The aim of inclining a still is to increase the solar radiation, by catching it head on, rather than at an angle as with stills which lie flat. To do this constantly, as the sun rises and sets, would need someone to monitor the sun and turn the unit regularly, or a sophisticated automatic tracking and turning mechanism.

4.12 Condensate Heat Recovery

Heat recovery from the energy given out when water vapour condenses has generally not been attempted with small-scale solar distillation, unlike with larger-scale systems. It is known that the Ben Gurion Institute, and more latterly the Technion Institute in Israel has undertaken some experiments with heat recovery. In the simplest system, saline water is made to flow over the outside of the condensation plate before entering the still, but then this would reduce the amount of solar radiation passing through the plate. There may be scope for further research to overcome current difficulties with attempting heat recovery from solar distillation.

4.12 Emergency still

To provide emergency drinking water on land, a very simple still can be made.
It makes use of the moisture in the earth. All that is required is a plastic cover, a bowl or bucket, and a pebble.

4.13 Hybrid designs

There are a number of ways in which solar stills can usefully be combined with another function of technology. Three examples are given:

• Rainwater collection. By adding an external gutter, the still cover can be used for rainwater collection to supplement the solar still output.

• Greenhouse-solar still. The roof of a greenhouse can be used as the cover of a still.

• Supplementary heating. Waste heat from an engine or the condenser of a refrigerator can be used as an additional energy input.

4.13 Output of a solar still

An approximate method of estimating the output of a solar still is given by:

Q = E x G x A

where:

Q = daily output of distilled water (litres/day)

E = overall efficiency

G = daily global solar irradiation (MJ/m^2)

A = aperture area of the still ie, the plan areas for a simple basin still (^{2})

In a typical country the average, daily, global solar irradiation is typically 18.0 MJ/m^2 (5 kWh/m^2). A

simple basin still operates at an overall efficiency of about 30%. Hence the output per square metre

of area is:

daily output = 0.30 x 18.0 x 1

2.3

= 2.3 litres (per square metre)

Performance varies between tropical locations but not significantly. An average output of 2.3 to 3.0

litres/m^2/day is typical, the yearly output of a solar still is often therefore referred to as approximately

one cubic metre per square metre, $1m^3/m^2$/year.

4.14 Experience

Despite a proliferation of more sophisticated designs such as TERI's solar desalination unit with offset collectors, the single-basin still has the best track record in the field. Hundreds of smaller stills are operating, in Africa and India.

The cost of pure water produced depends on:

• the cost of making the still
• the cost of the land
• the life of the still
• operating costs
• cost of the feed water
• the discount rate adopted
• the amount of water produced.

An example of costs of a solar still in India is Rs. 28000 for 15 m^2 approximately $575.00 for 15$m^2$, or $38.3 per m^2. The price of land will normally be a small proportion of this in rural areas, but may be prohibitive in towns and cities.

The life of a glass still is usually taken as 20 to 30 years but operating costs can be large especially to replace broken glass.

It is important that stills are regularly inspected and maintained to retain their efficiency and reduce deterioration. Damage, such as breakage of the collector plate, needs to be rectified.

Some companies, e.g. in the United States, Russia, India and South Africa, sell solar stills, largely for household use to produce up to about 50 litres per day.

4.15 Solar still as per the needs

People need 1 or 2 litres of drinking water a day to live. The minimum requirement for normal life in developing countries (which includes cooking, cleaning and washing clothes) is 20 litres per day (in the industrialised countries 200 to 400 litres per day is typical). Yet some functions can be performed with salty water and a typical requirement for distilled water is 5 litres per person per day. Therefore 2m^2 of still are needed for each person.

Solar stills should normally only be considered for removing dissolved salts from water. If there is a choice between brackish ground water or polluted surface water, it will usually be cheaper to use a slow sand filter or other treatment device. If there is no fresh water then the main alternatives are desalination, transportation and rainwater collection.

Unlike other techniques of desalination, solar stills are more attractive, the smaller the required output. The initial capital cost of stills is roughly proportional to capacity, whereas other methods have significant economies of scale. For the individual household, therefore, the solar still is mosteconomic.

For outputs of 1m³/day or more, reverse osmosis or electrodialysis should be considered as an alternative to solar stills. Much will depend on the availability and price of electrical power.

For outputs of 200m³/day or more, vapour compression or flash evaporation will normally be least cost. The latter technology can have part of its energy requirement met by solar water heaters.

In many parts of the world, fresh water is transported from another region or location by boat, train, truck or pipeline. The cost of water transported by vehicles is typically of the same order of magnitude as that produced by solar stills. A pipeline may be less expensive for very large quantities.

Rainwater collection is an even simpler technique than solar distillation and is preferable in areas with 400mm of rain annually, but requires a greater area and usually a larger storage tank. If ready-made collection surfaces exist (such as house roofs) these may provide a less expensive source for obtaining clean.

Chapter 5

PROJECT WORK AND EXPERIMENTATION

5.1 General

The drying process removes moisture.The disadvantages associated with open drying is that dust get embedded into the clothes.Also when there is no sunlight and considerable humidity,the drying can take a longer time.There are dryers in washing machines,but they dry by centrifugal action and are unable to perfectly dry the clothes.With a solar dryer,drying can be done quicker,eliminating the drawbacks in existing drying methods.Even during the winters when there is scarce sunlight,the dryer can be operated by switching on the auxiliary heating forced convection system,with a minimal expenditure of energy.

5.2 Objectives

→ To fabricate a model of solar cloth dryer.

→ To provide a cost effective solar direct heating system for drying of clothes.

→ To provide a sustainable dryer that uses green energy that can replace the electricity consuming dryers.

5.3 System description and experimentation

In designing the collector of this system to capture the solar heat,GP steel sheets of 1mm thickness was used. The sheets were cut as per the dimensions shown in the figure to make an assembly of the outer box,by spot-weding the sheets together.Holes of radius 6" for forced convection by fitting in blower, were cut out on the sheets, before welding the assembly, using circle cutters on the two opposite sides of the box,approximately 8" from the bottom.Leaving a space of about 1" from all the walls of the outer box,A similar box,of slightly reduced dimensions,was made that would go in and fit well within the outer box,with a layer of insulation separating them. Holes of 6" were also made into this box.The insulation layers were made by stuffing in thermocol slabs of 1" thickness between the two boxes.A fan (6" sweep,1400 rpm,240 V,40 watt) was fit on the outer side along with an infrared heating bulb of 245 watts to provide for the auxiliary heating. Aluminium sliders were designed to fit on the slanting upper part where glass can slide in and out. Stoppers were made at the end of the sliding channels to prevent the glass falling through.A collector channel was made to collect the condensed water

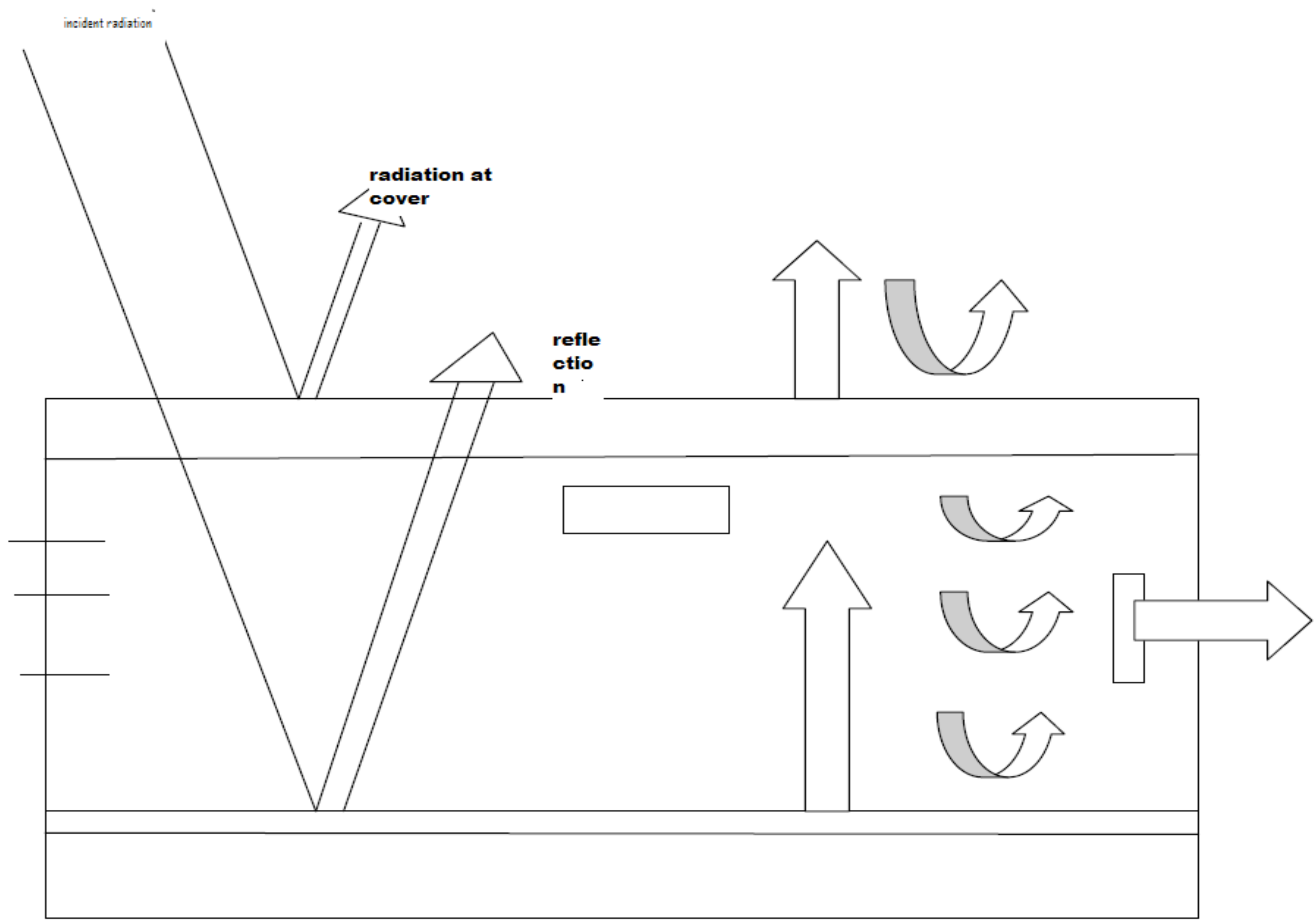

Fig.5.1 Working principle

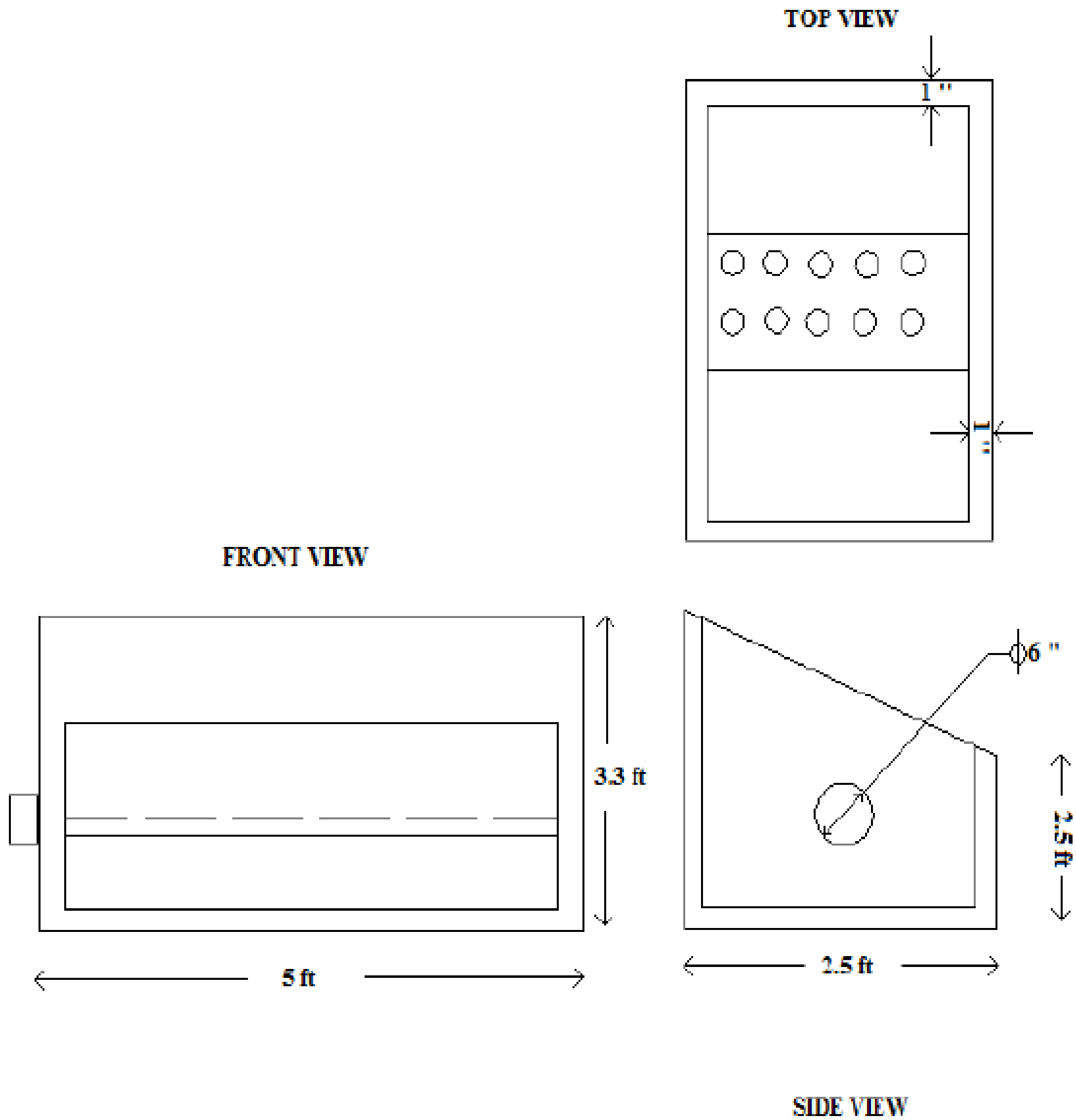

Fig. 5.2 Dimensions of the dryer

from the slanting glass.The angle of slant was fixed as 16º for optimum collection of solar radiation.Finally,a glass slab (3.5 mm thickness) of dimensions 4.8 ft×2.6 ft was slid in.A tray system was welded on the inner side of the inner box to dry the clothes.This was done before the final assembly.Experiments were performed with thermometer and stopclock by putting in the clothes,under sunlight and inside the room.The figures show the dimensions and final photos of the made assembly.

Fig. 5.3 Operation of the dryer

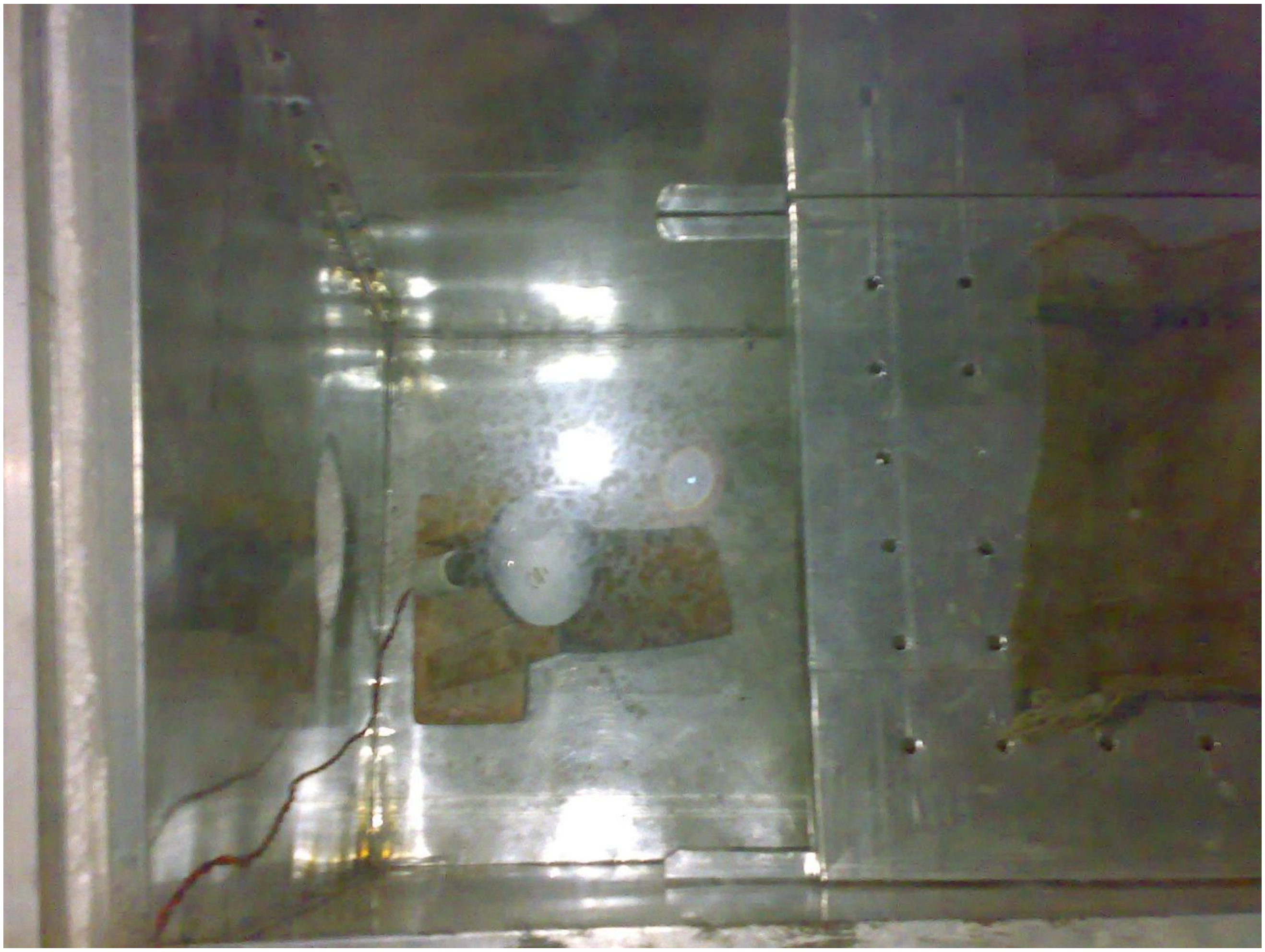

Fig 5.4 tray along with the infrared heating bulb

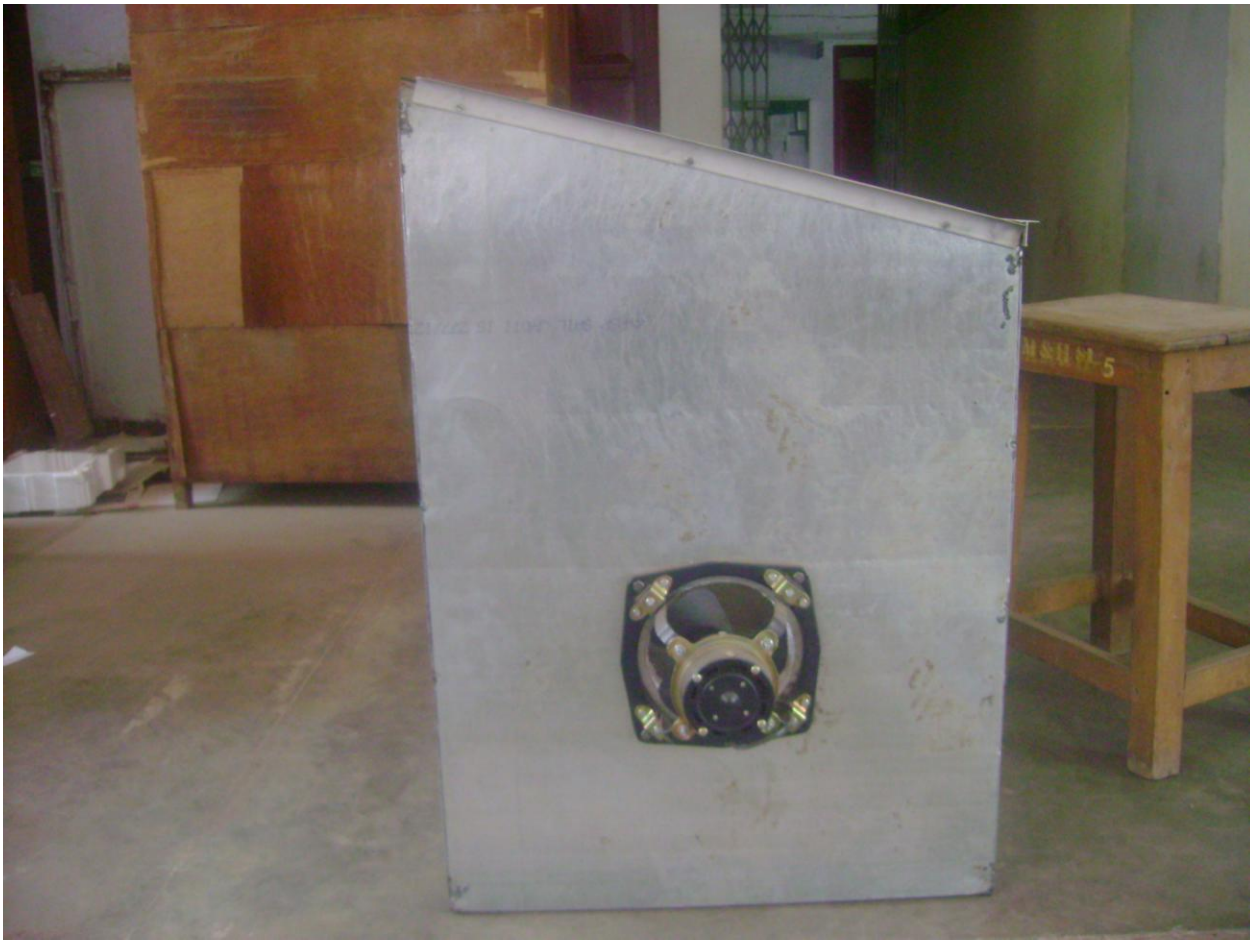

Fig. 5.5 inlet side

Fig. 5.6 exhaust side

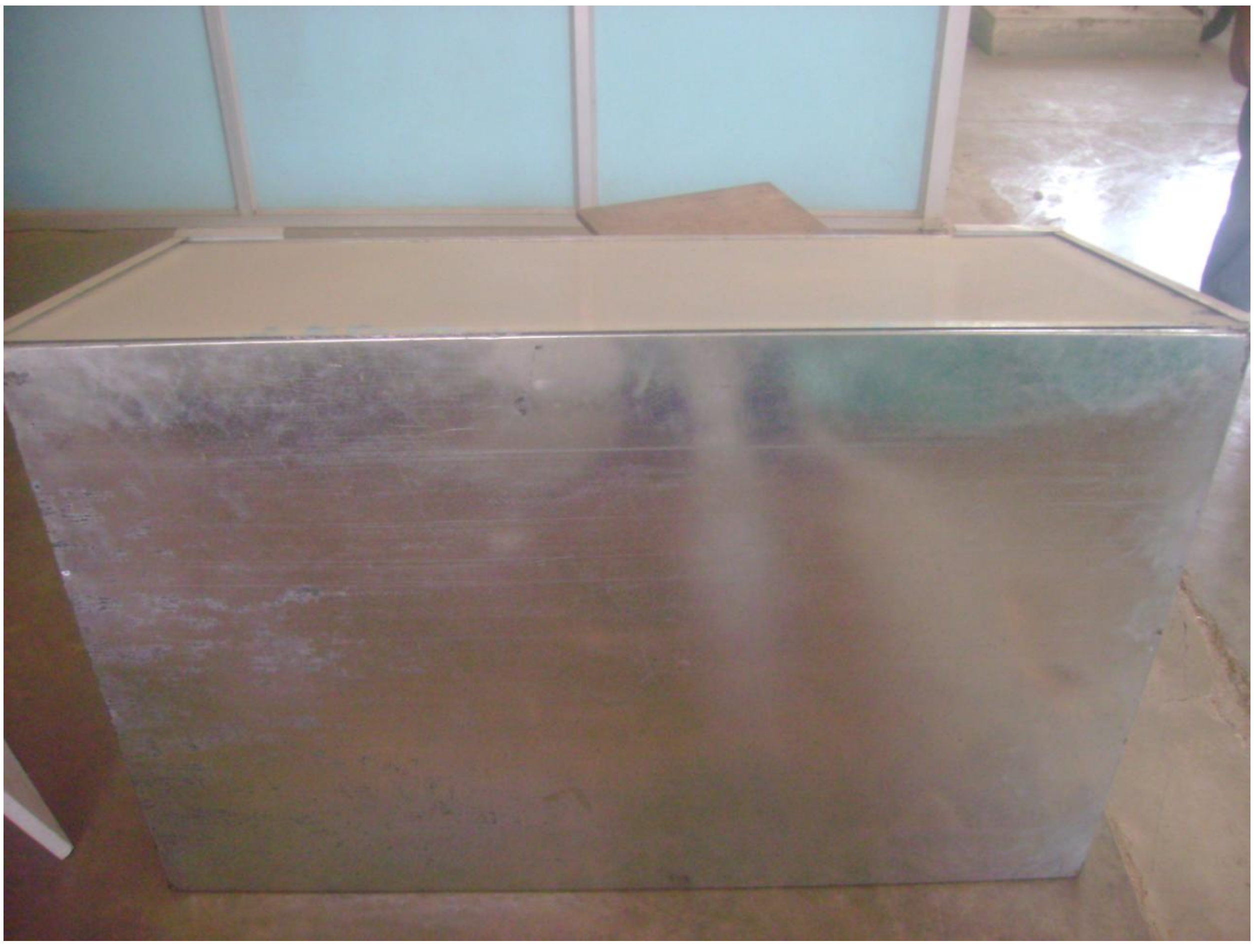

Fig. 5.7 backside

Chapter 6
RESULTS AND DISCUSSION

6.1 General

After assembling the the solar dryer,a set of experiments were performed to test its efficacy.The experiments were carried out on days of bright sun and inside the room to simlulate a non-sunny day.Five T-shirts were used as testing subjects,one after another adding up to see the variation.The following parameters were studied and graphed during the experimentation of the dryer:

6.2 No. of clothes Vs time(minutes) taken for drying with solar radiation

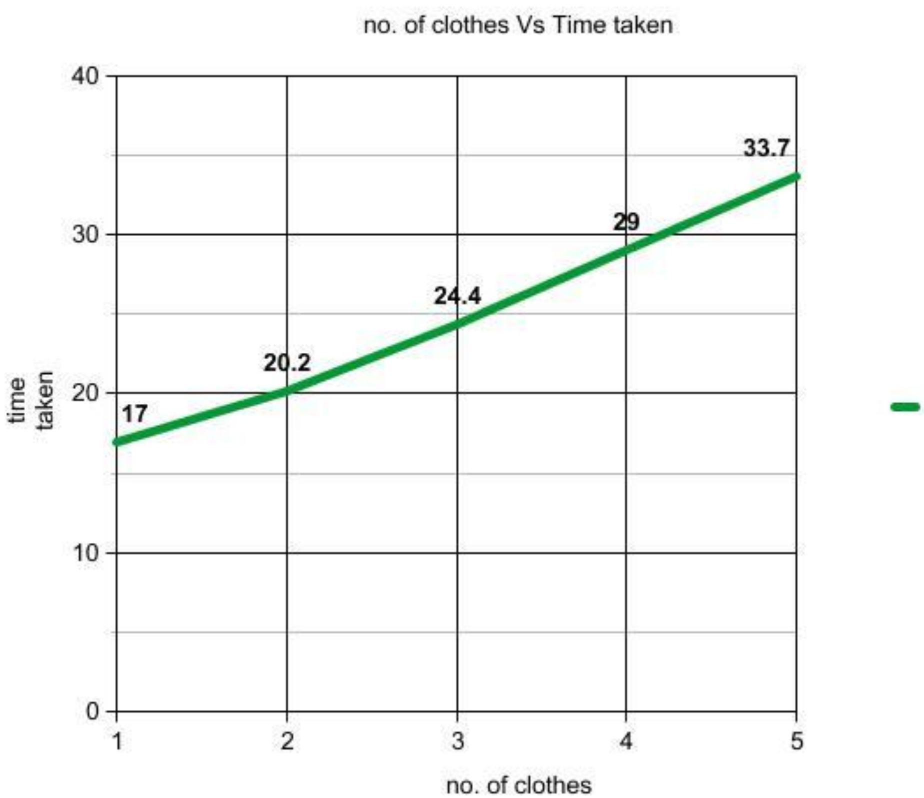

Fig. 6.1

6.3 No. of clothes Vs time(minutes) taken without solar radiation

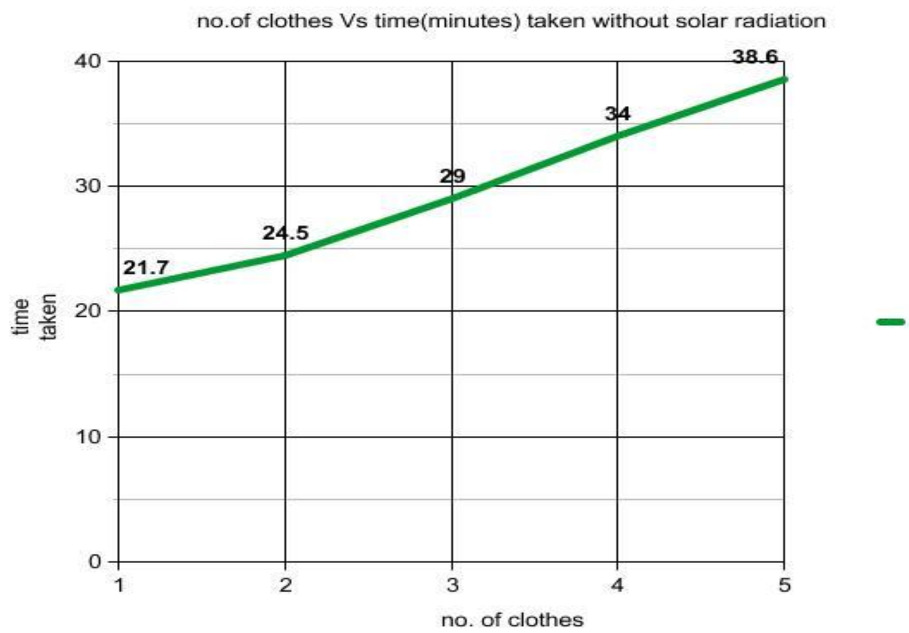

Fig. 6.2

6.4 Moiture removal(%) Vs time taken(minutes) for solar radiation

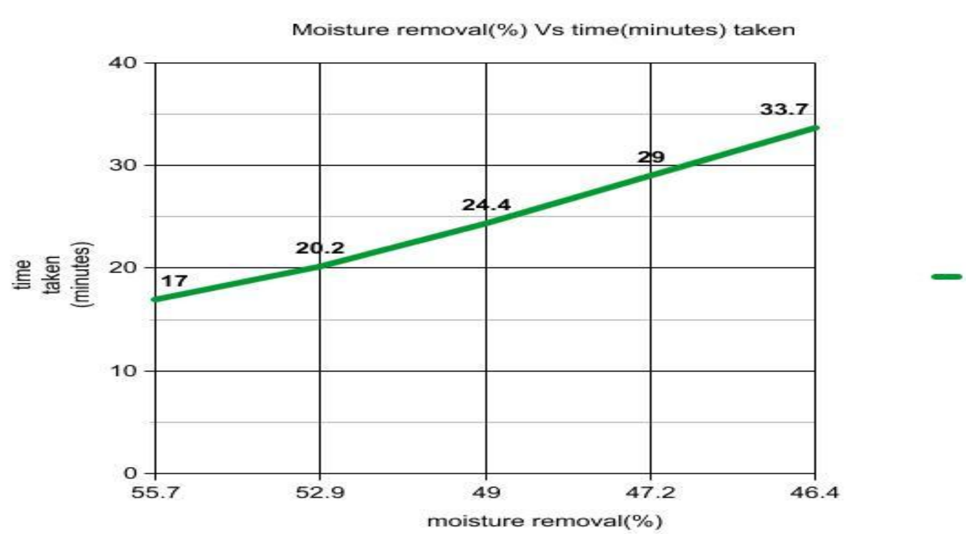

Fig. 6.3

6.5 Outlet temperature Vs no. of clothes without solar radiation

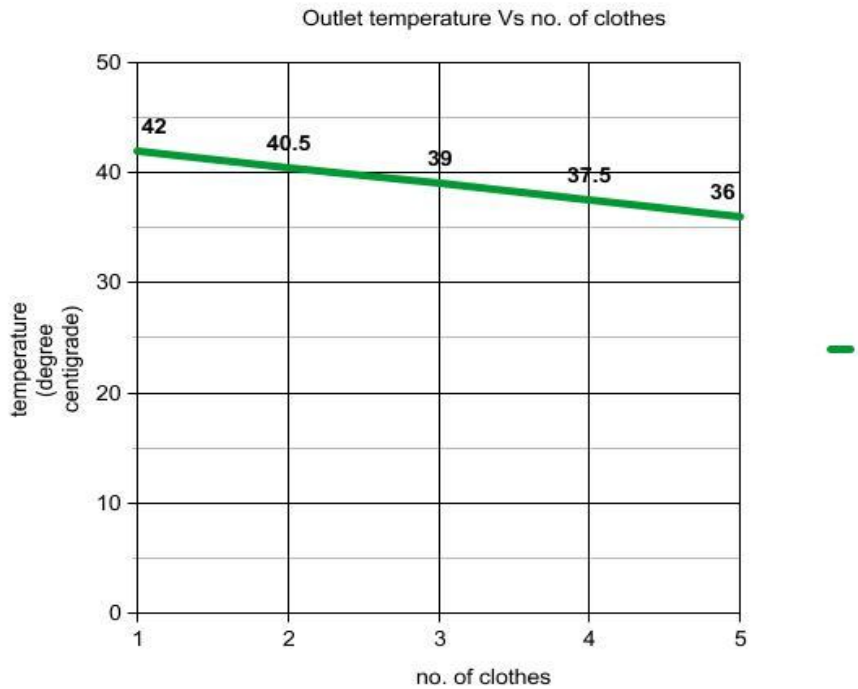

Fig. 6.4

6.6 No. of clothes Vs power (in kJ) consumed

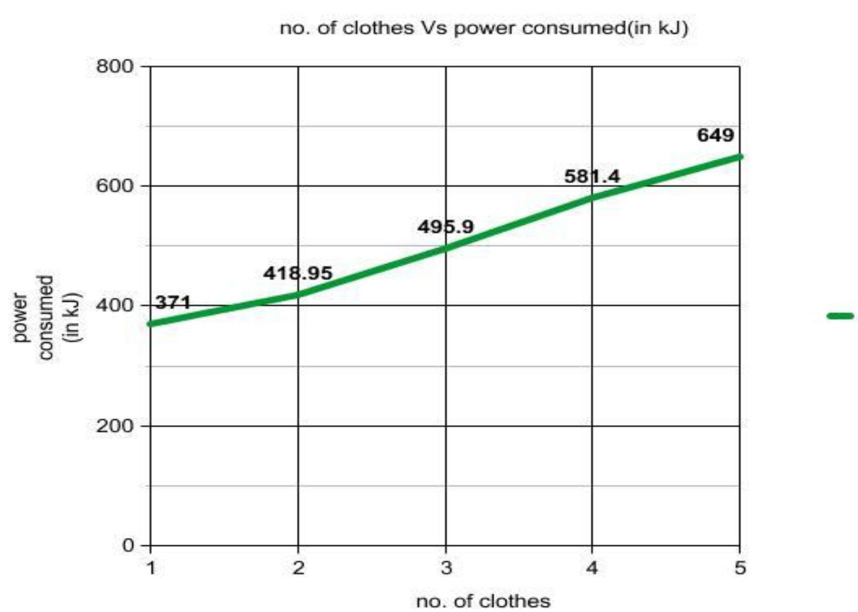

Fig. 6.5

6.7 Discussion

In Fig. 6.1,the time taken to dry up for each step of the experiment increases in almost linear trend.Thus the time taken for the clothes to dry up is a linear function of the number of clothes used.It is to be noted that the slope of the curve for the second step to the last is greater than than of the first to the second.This may be attributed to increased local humidity during the experiment and the distribution of heat among the other clothes.The temperature reading inside the chamber was observed as 52ºC.

In Fig.6.2,the the curve is almost the same as that during solar radiation.The curve between step 2 and 5 has a lesser slope as compared to the same in Fig 6.3.This can be reasoned as due to better dispersal of moisture because of forced convection.Also,the time taken by the clothes to dry up is significantly higher than that in the first case.The thermometer reading inside the chamber during the experiment was observed as 46ºC.

In Fig. 6.3,the graph is found to be almost linear in nature.Thus moisture removal is a linear function of the number of clothes used.

In Fig. 6.4,the curve shows a trend wherein the the measured outlet temperature goes on decreasing with the number of clothes used.This is because the heat from the heater lamp goes into drying the kept clothes,thereby decreasing the overall heat content in the outlet air.Thus,the outlet temperatue is inversely proportional to the number of clothes used,and the curve is approximately linear.

In Fig. 6.5,the graph is almost linear,except for the portion between the 1st and the 2nd steps,where the slope is less,which indicates less power consumption.The consumption increases because of the increased drying time of more clothes inside the chamber.

Chapter 7
CONCLUSION

7.1 Summary

A solar cloth dryer has been fabricated from locally available materials and tested under real climatic conditions.The maximum temperature recorded during functioning under solar radiation was found to be 52ºC and that during non-sunny operation under forced convection was observed as 46ºC,when the ambient temperature inside the room was 41ºC.Since solar energy is diffusive in nature and provides low grade heat,this characteristic of solar energy is good for the drying at low temperatures,high flow rates with low temperature rise.The intermittent nature of solar radiation will not affect the drying performance at low temperature,as the energy stored in the product itself will help in de-moisturising in periods of no sunshine.

The experiments performed show that the dryer dries up clothes quicker than existing methods.The main significant advantage is that it has no moving parts,which makes its operation more easy and also consumes lesser power than the dryer in machines.The whole set-up can be made easily from existing materials at a cost of Rs.8000 approx.Also,since it is a closed chamber,dirt from outside can hardly affect the clothes inside.The result is a uniform, clean and efficient drying.In places like hospitals,this set-up can be scaled up at the terraces to dry a good number of clothes in quick time.This set-up can also be extended for use in the agricultural industry like drying of seeds.

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